Fermi National Accelerator Laboratory

New CDF End-Plug Calorimeter

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Abstract

The performance of the CDF end-plug calorimeter is described. We determined the energy resolutions to be $\sigma/E = 14.5\%/\sqrt{E} \oplus 0.7\%$ for electron and $\sigma/E = 68.0\%/\sqrt{E} \oplus 4.1\%$ for charged pion, where E is the energy measured in GeV. The response linearities satisfied our requirements. The response variations on the surface of a typical tower were measured to be 2.3% for e^+ and 1.6% for π^+. For the photon conversion detection by the preshower detector, we obtained the detection efficiency for two minimum ionizing particles to be $90-100\%$ for the phototube gains of $(1-4)\times10^5$. The rate of π^+'s depositing large fractions of energy in the electromagnetic section could be reduced by factors of $1.4-2.0$ with keeping 95% efficiency for e^+.

1   Introduction

Extensive changes are required to the experimental apparatus of the CDF detector due to the high luminosity Tevatron accelerator. The CDF end-plug calorimeter is upgraded to substitute a sampling plastic-scintillator calorimeter for the sampling gas calorimeter to match the operation condition of the Tevatron, especially shorter bunch spacing of 132 nsec. The new CDF end-plug calorimeter covers the polar angle from $\theta = 3°$ to $38°$ and consists of

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[1] Members of the following CDF institutions participate in the Plug Upgrade: INFN University of Bologna, Brandeis University, Fermilab, KEK, Michigan State University, Purdue University, University of Rochester, Rockefeller University, Texas Tech University, Universita di Udine, University of Tsukuba, UCLA, Waseda University, University of Wisconsin.

an electromagnetic (EM) section followed by a hadronic (HAD) section. The active elements are 4 mm (6 mm) thick plastic scintillator tiles, and the absorber elements are 4.5 mm lead (2 inch steel) plates in the EM (HAD) section. Wave length shifter fibers embedded in each scintillator tile are spliced to clear fibers to carry lights out to photomultiplier tubes (PMT's). There are 23 (22) layers in depth for total thickness of $21X_0$ ($7\lambda_I$) in the EM (HAD) section. The first layer in the EM section has a separate readout system to be used as a preshower detector for statistical separation between single γ and $\pi^0 \rightarrow \gamma\gamma$. A position sensitive detector consisting of 5 mm wide scintillator strips is installed at the shower maximum position ($\simeq 6X_0$). Requirements of the energy resolution (σ/E) and the response non-linearity (η) are $\sigma/E = 16\%/\sqrt{E} \oplus 1\%$ ($\sigma/E = 80\%/\sqrt{E} \oplus 5\%$) and $|\eta| < 1\%$ ($|\eta| < 5\%$) for e^+ (π^+), respectively[2]. Detail descriptions are available in Refs. [1].

2   Performance of the Calorimeter

Beam tests were carried out at Fermilab. A test module consisting of a 45° section EM calorimeter followed by a 60° section HAD calorimeter was constructed in a manner identical to the actual detector. We used beams of positive e, π and μ particles with energies of $5-227$ GeV/c. The purity of e^+ beam was estimated to be $> 99\%$. Two pairs of single wire drift chambers were installed at upstream and downstream of bending magnets to measure the beam momentum with accuracy of $\Delta p/p < 1.6\%$.

A laser calibration system [2] is used to monitor the stability of the PMT gains. In addition, a ^{137}Cs radioactive movable wire source which exposes individual scintillator tile is used to equalize responses of the real detector [3]. We found that the correlation between the response to the wire source and 57 GeV e^+ has a spread of $\simeq 2\%$. We expect a $\simeq 2\%$ response variation for the real detector at the start of next physics run.

The response to e^+ of the preshower detector was added to the total response with a proper weight factor to improve the linearity and the energy resolution. The responses to the pion beams were corrected for proton contaminations[3]. The differences of the available energy, π^0 fraction in hadron shower (F_{π^0}), and interaction length were considered [4]. Figures 1 and 2 show the energy resolution and the non-linearity of responses at the center of a typical tower as

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[2]   The definition of the non-linearity is $\eta = \langle E/p \rangle - 1$, where E is the measured energy, p is the particle momentum and $\langle E/p \rangle$ is the average of E/p normalized by that at p=122 GeV/c. The symbol $\oplus$ indicates a sum in quadrature.

[3]   The proton contaminations were estimated from a beam line simulation (DECAY-TURTLE) and direct measurements at p=5.4 and 13.3 GeV/c.

a function of energy for e^+ and π^+, respectively. In Fig. 2, the square symbol shows the response to π^+'s which are minimum ionizing particles (mip's) in the EM section, the triangle symbol shows the response to π^+'s interacting either in the EM or HAD section. We obtained the energy resolution of $\sigma/E = 14.5\%/\sqrt{E} \oplus 0.7\%$ and the non-linearity of $|\eta| < 2\%$ for e^+, and $\sigma/E = 68.0\%/\sqrt{E} \oplus 4.1\%$ and $|\eta| < 5\%$ for π^+. The energy resolutions and the non-linearities for e^+ and π^+ satisfy our requirements.
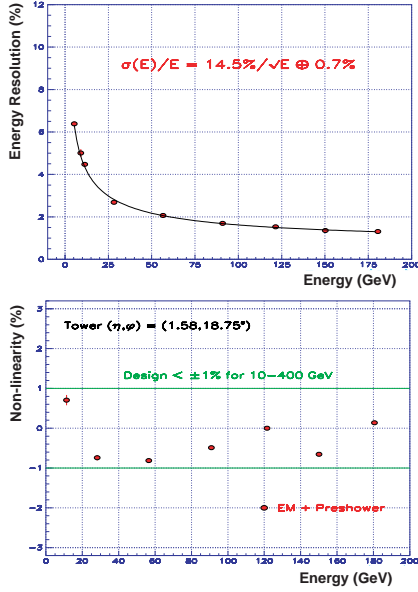

Fig. 1. Energy resolution and response non-linearity (η) as a function of energy of e^+.
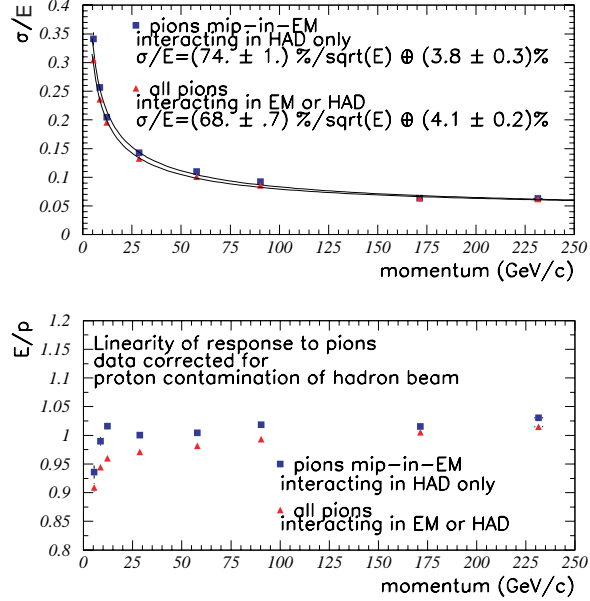
Fig. 2. Energy resolution and response linearity as a function of energy of π^+.

Transverse responses inside a typical tower were measured using a fine position-scanning test beam data for 57 GeV e^+ and π^+. The response variation inside the tower is 2.3% for e^+ and 1.6% for π^+. The transverse non-uniformity for e^+ could be reduced to $\sim$1% for the real detector by applying the average response map obtained from the beam test [5].

We extracted the response ratio electron/hadron (e/h) from the electron/pion ratio (e/π) after correcting for the proton contamination and the longitudinal shower leakage [4]. We estimated e/h=1.34$\pm$0.01 for $F_{\pi^0} = 0.11 \times \log E$ [6] and e/h=1.42$\pm$0.02 for $F_{\pi^0} = 1 - (E/0.96)^{-0.184}$ [7].

3 Performance of the Preshower Detector

The performance of the preshower detector was estimated from the test beam data. For photon conversion detection, a pulse height distribution for two mip's was simulated based on two distributions for one mip responses. From

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the simulated distribution, the detection efficiency for two mip's was found to be 90%−100% with < 1% noise occupancy for the gains of $(1-4)\times10^5$. For rejection of π^+'s depositing large fraction of energy in the EM section, we obtained additional reduction factors of 1.4−2.0 (1.4−2.8) while keeping 95% (90%) of e^+.

4 Conclusions

We obtained the performance of the CDF end-plug calorimeter based on the tile/fiber technology from the beam test data. We obtained the energy resolutions of $\sigma/E = 14.5\%/\sqrt{E} \oplus 0.7\%$ ($\sigma/E = 68.0\%/\sqrt{E} \oplus 4.1\%$), while the requirement is $\sigma/E = 16\%/\sqrt{E} \oplus 1\%$ ($\sigma/E = 70\%/\sqrt{E} \oplus 5\%$) for e^+ (π^+). The non-linearity of responses to e^+ (π^+) satisfied our requirement of $|\eta| < 2\%$ ($|\eta| < 5\%$). The calorimeter achieved the detector performance of our design requirements.

The detection efficiency for 2 mip's in the preshower detector was found to be 90−100% for the gains of $(1-4)\times10^5$ with < 1% noise occupancy. By requiring high energy deposition in the preshower detector, additional reduction factors of 1.4−2.0 against π^+'s depositing large fractions of energy in the EM section was achieved while keeping 95% of e^+.

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